satellite antenna shown in Figure 5.1. (Keep in mind, however, that this is only a snapshot of the required exclusion zone at the instant the mainbeam of the feederlink terminal is pointed at the GSO satellite during the in-line event. As the MEO satellite that it is tracking moves away from the feederlink terminal and out of the GSO satellite line-of-sight, the exclusion zone will quickly shrink back to zero). However, this is clearly an impractical solution to alleviating the interference.

One might also consider simply keeping the MSS feederlink earth station antenna pointed away from the GSO satellite, thereby achieving the necessary isolation through the high gain/narrow beamwidth feederlink earth terminal, which is 7 meters in diameter in this case. However, this is not a practical solution either, due to the orbital dynamics of the problem. The orbit parameters of the 12 satellite MEO constellation result in 12 separate ground tracks (one satellite per track) on the earth's surface as shown in Figure 5.2. To a first order approximation, the 6 hour orbital period has ground tracks that repeat every 24 hours. The constellation is such that for locations between 50°N and 50°S latitude, at least two MEO satellites can be seen above a 10° elevation angle at any time. At first glance, it appears that one could take advantage of the gaps in the ground track pattern and coordinate the positions of GSO satellites with the ground track pattern so as to avoid these in-line interference events entirely. However, as indicated earlier, the pattern does not repeat precisely. Without continuous spacecraft maneuvering to maintain a repeating pattern, orbital perturbations (most significantly the perturbation due to the earth's non-spherical shape) will cause the orbit planes to precess westward at a rate of about 0.2° per day. As a result, the pattern in Figure 5.2 will always be slowly shifting so that *no matter where a feederlink terminal is located and no matter where the GSO satellites are positioned, the feederlink terminal will sooner or later have its mainbeam momentarily pointed towards a GSO satellite while it is in the process of tracking one of its MEO satellites* (assuming the GSO satellite is visible from the feederlink location).

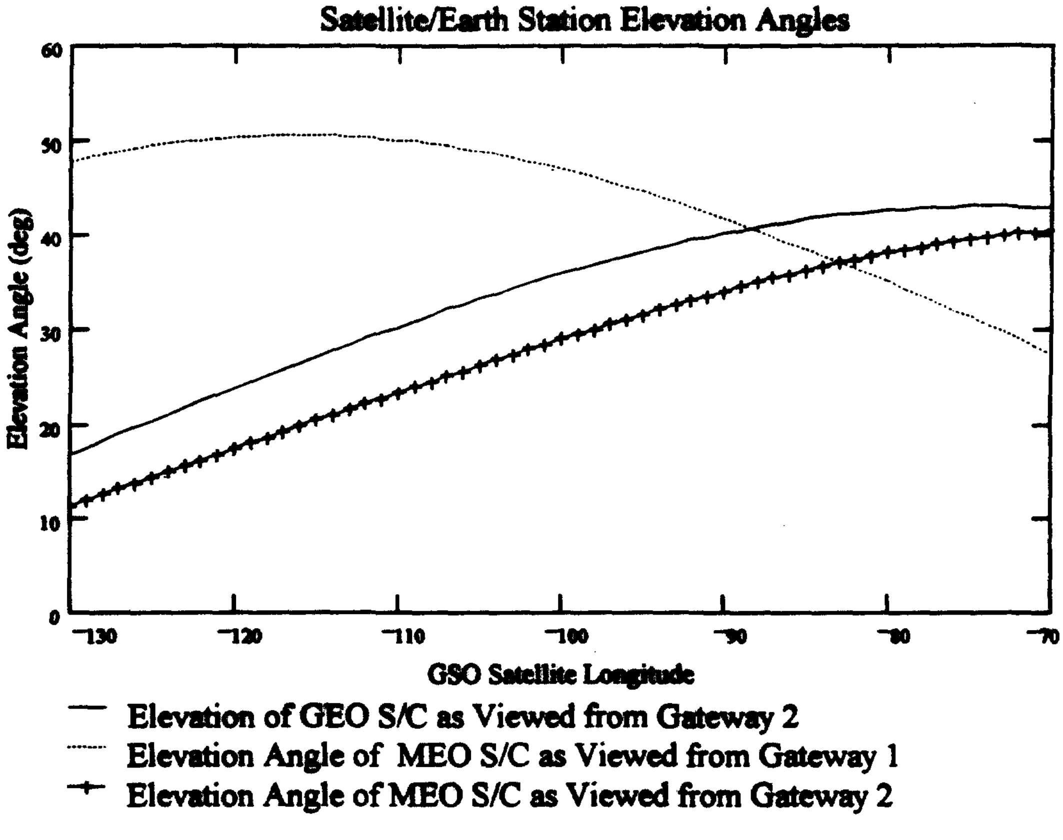
Other mitigation techniques such as adaptive power control and use of higher gain/sharper rolloff antennas were also briefly considered, but did not appear to be viable solutions due to the very high levels of isolation required, typically 20-30 dB as shown in Table 4.9. While the use of higher gain/sharper rolloff antennas is helpful in a "static" interference environment where (GSO) satellites and earth stations are not moving relative to each other, in a dynamic interference environment where there is relative motion the antennas would introduce opposing effects. That is, although interference events may not last as long due to the narrower beamwidths of the antennas, when they do occur, they cause higher peak levels of interference by virtue of their higher gain. In conjunction with other techniques such as site diversity, however, high gain/narrow beamwidth antennas such as those of the MSS feederlink terminal can be a definite advantage.

The MSS MEO system in this study has no intersatellite links between the satellites in the constellation and the use of "orbit avoidance" to solve the interference problem is not possible (i.e., in orbit avoidance, a feederlink station wanting to communicate with a LEO or MEO satellite which is in-line with an interfering GSO satellite would do so by communicating with a neighboring satellite which is not in-line subsequently routing the traffic to the intended satellite via an intersatellite link).

Four features of this particular MEO system, however, make feederlink site diversity an attractive possibility for mitigating interference. With this approach, an alternate feederlink path is established with the MEO satellite from a second feederlink terminal while it is in-line with a GSO satellite from the point of view of the original feederlink terminal (See Figure 5.3).

First, the gateways for this system are planned to have wide geographic separation with one on the West coast of CONUS and another on the East coast. Each gateway facility is assumed to have up to four separate feederlink earth stations for tracking the satellites. For this study we assume the West coast gateway (Gateway 1) is located near San Diego, California at 34°N, 116°W and the East coast gateway (Gateway 2) is located near Philadelphia at 40.7°N, 74°W.

Second, the altitude of the MEO orbit is high enough that a MEO satellite which may be causing an in-line interference event is simultaneously visible to both East and West coast gateways. A plot of the elevation angle from the two gateways to the MEO and GSO satellites over a range of GSO satellite longitudes is shown below.



(Note that since we are considering the MEO S/C to be "in-line" with respect to Gateway 1, the elevation angle of the GEO S/C as viewed from Gateway 1 is just the same as the elevation angle of the MEO S/C as viewed from Gateway 1 which is why there are only three curves instead of four).

It can be seen that even when the MEO satellite is causing an in-line event for a GSO satellite located as far west as 130°, it is still visible above 10° elevation angle to the East coast gateway.

The third reason this MEO/MSS system lends itself to site diversity is that each of the satellites has three independently steerable dual-band (30/20 GHz) feederlink antennas which all transmit and receive the same 300 MHz FDM feederlink signal and therefore is capable of rapid handoffs with up to three geographically separate feederlink terminals.

Lastly, the 7 meter feederlink terminals have high enough gain that a large amount of antenna discrimination is achieved for values of the off-axis angle α shown in Figure 5.3. Referring to Figure 5.3, the off-axis angle α varies from about 7°-12° over the GSO longitude range 130°W-70°W. *At a typical off-axis angle of α=10°, the feederlink terminal transmit antenna fall-off is 56.8 dB while the receive antenna fall-off is 52.8 dB.*

The effect of using feederlink diversity to suppress interference on the four interference paths is shown in Figure 5.4 and 5.5. **All these plots refer to the geometry shown in Figure 5.3.**

Figure 5.4(a) *show the peak* I/N_T ratios on the four interference paths as a function of the GSO satellite longitude which occur during an in-line event as viewed from an MSS feederlink station located at the West coast gateway. The I/N_T will vary with time due to the relative motion of the MEO satellites, but for a given GSO satellite longitude, the peak value will occur at the instant when the MEO satellite appears along the line-of-sight between the West coast MSS feederlink station and the GSO satellite. Assuming there are GSO earth stations co-located with the MSS feederlink station, mainbeam coupling then occurs between the MSS and FSS satellites and earth stations. It can be seen that the peak I/N_T values are nearly constant over the GSO satellite longitude range since the only thing that is changing in this case are the slant ranges between satellites and earth stations. It can also be seen that the peak I/N_T values on all four interference paths exceed the maximum allowable I/N_T value of 11.7 dB.

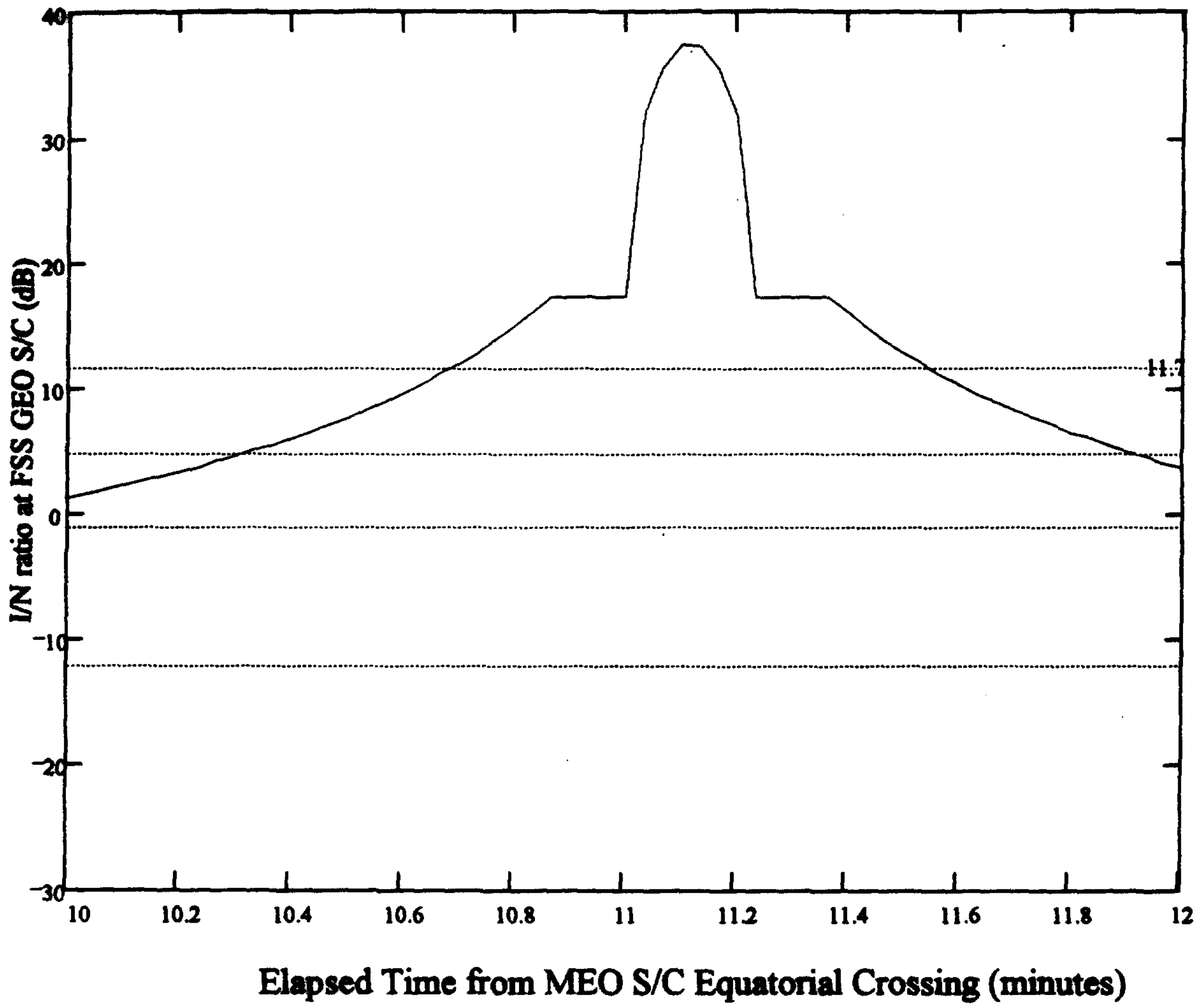
Given that the in-line MEO satellite is simultaneously visible to both gateway sites over the 130°W-70°W GSO longitude range, Figure 5.4(b) shows the peak I/N_T values for the alternate East coast gateway feederlink. The peak I/N_T values are now well within the acceptable levels, and for most GSO orbital positions, are even well below the "negligible" I/N_T value of -12.2 dB. *It is also important to note that the East coast gateway facility is itself assumed to be within a co-frequency spot beam of the GSO satellite and has GSO FSS earth stations co-located with it.* In other words, sufficient isolation is achievable through earth station antenna discrimination alone. Since the values shown in the plot are *peak* values and are all below the -12.2 dB I/N_T criterion for most GSO orbital positions, there is no need to obtain time statistics through computer simulation (i.e., the percent times will all be zero). Simulation would, however, enable one to determine when a gateway handoff is required according to some desired interference threshold. Figure 5.5(a) and (b) show similar results when the gateway sites are located in wide spot beams of the GSO satellite.

In conclusion, it appears that co-frequency sharing between the NGSO-MEO and FSS GEO systems considered in this paper is feasible through the appropriate application of MSS feederlink site diversity. With feederlink sites on the East and West coasts of the U.S., the establishment of an alternate feederlink path from one gateway site while the other gateway site is experiencing an in-line interference event, is sufficient to maintain interference levels on the various transmission paths within acceptable limits.

6.0 Conclusion

In this study, the sharing situation between a NGSO MEO MSS satellite system and a GSO FSS system in the 30/20 GHz band was examined. The MEO constellation presents several unique problems to the sharing situation that are not present when considering the LEO satellite constellations. The MEO satellites are at a much higher altitude and therefore travel at a much slower rate across the sky. Their dwell times are therefore much longer than those of LEO satellite systems. Also, the high altitude allows the MEO satellites to have much wider coverage areas than the LEO systems which can contribute to the interference scenarios. Finally, the NGSO MEO MSS system examined in this paper has very large feederlink antennas further exacerbating the problem. These unique features also lead to a unique potential solution to the interference problems. Through proper application of MSS feederlink site diversity, co-directional frequency sharing between the NGSO MEO MSS feederlinks and the GSO FSS satellite system operating in the 30/20 GHz band is feasible.

Figure 4.1 - I/N Ratio (dB) at GSO FSS Satellite Due To Interference From MEO MSS Feederlink Earth Station Located at 34° N Latitude, GSO Satellite Narrow Spot Beam



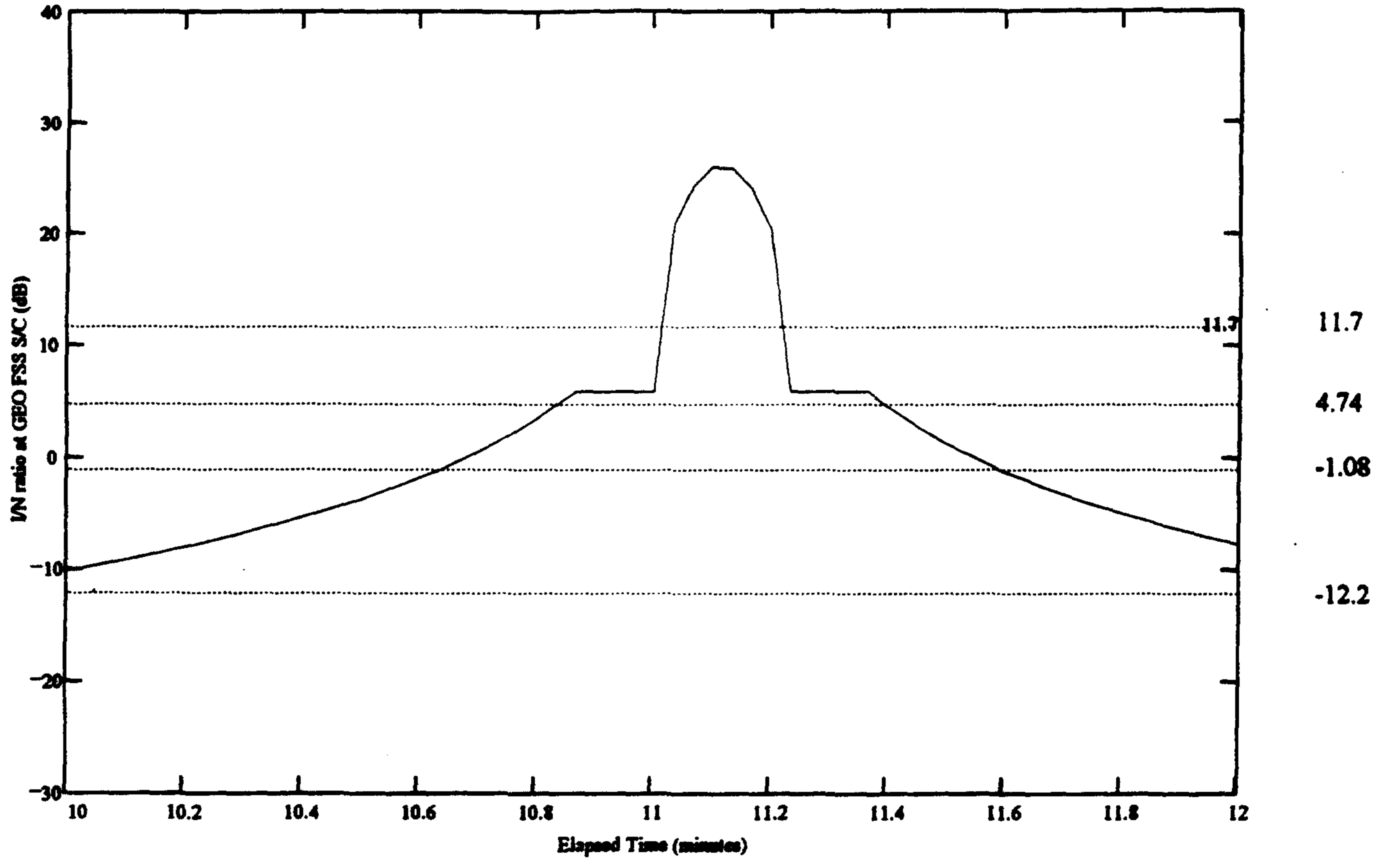
Note: The threshold lines on this plot represent the four interference levels of I/N in dBs:

I/N = 14.8 = 11.7 dB (cannot be exceeded more than 0.0004% of the time)
I/N = 2.98 = 4.74 dB (cannot be exceeded more than 0.0294% of the time)
I/N = 0.78 = -1.08 dB (cannot be exceeded more than 0.119% of the time)
I/N = 0.06 = -12.2 dB (cannot be exceeded more than 0.87% of the time)

FIGURE 4.2

I/N Ratio (dB) at GEO FSS Satellite due to Interference from MEO MSS Feederlink Earth Station

(34°N latitude; Wide Spot Beam)

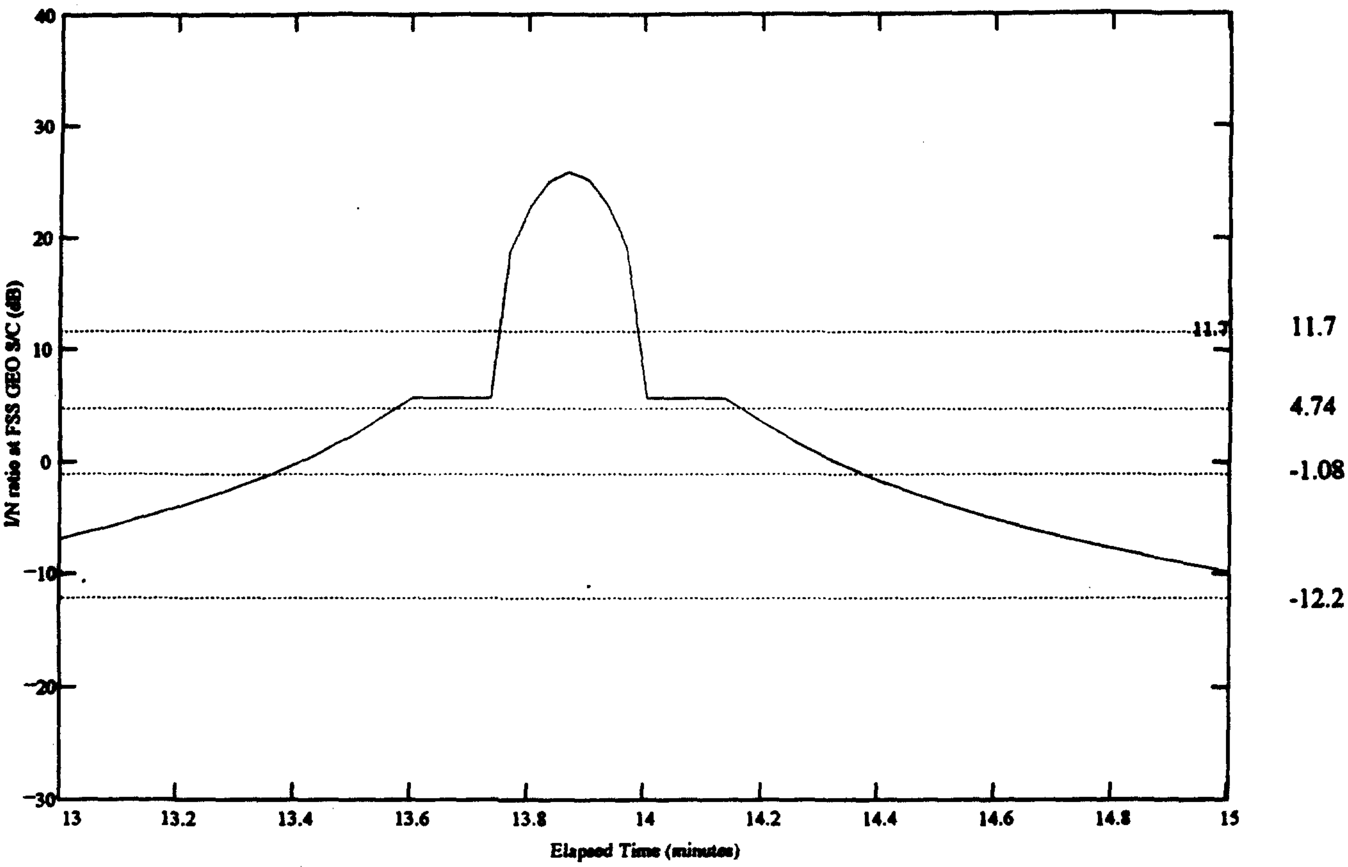


Elapsed Time from MEO S/C Equatorial Crossing (minutes)

FIGURE 4.3

I/N Ratio (dB) at GEO FSS Satellite due to Interference from MEO MSS Feederlink Earth Station

(45°N latitude; Wide Spot Beam)

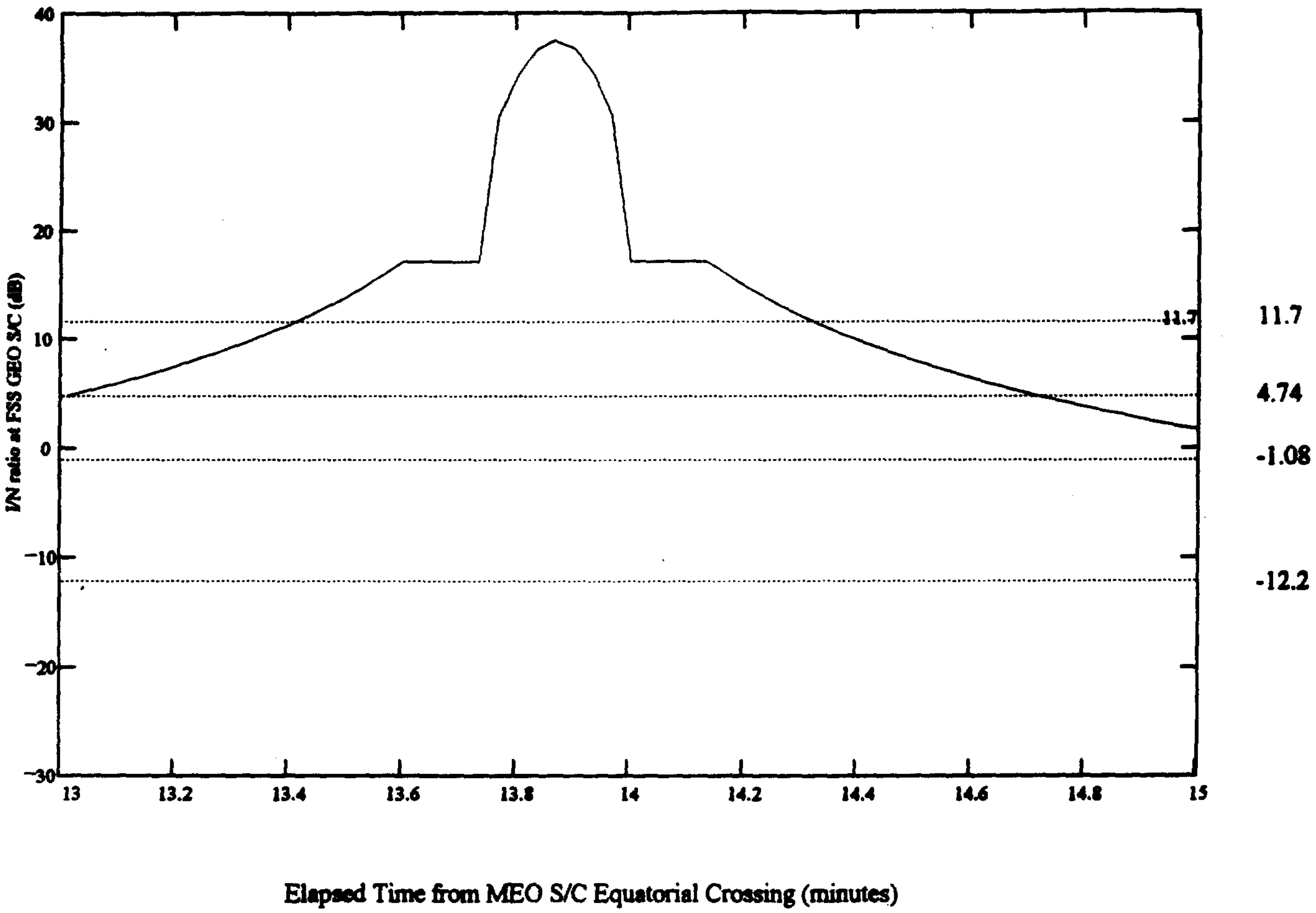


Elapsed Time from MEO S/C Equatorial Crossing (minutes)

FIGURE 4.4

I/N Ratio (dB) at GEO FSS Satellite due to Interference from MEO MSS Feederlink Earth Station

(45°N latitude; Narrow Spot Beam)



FI RE 5.1

Gain Contours of GEO S/C Narrow (0.76°) Spot Beam Aimed at West Coast MSS Gateway

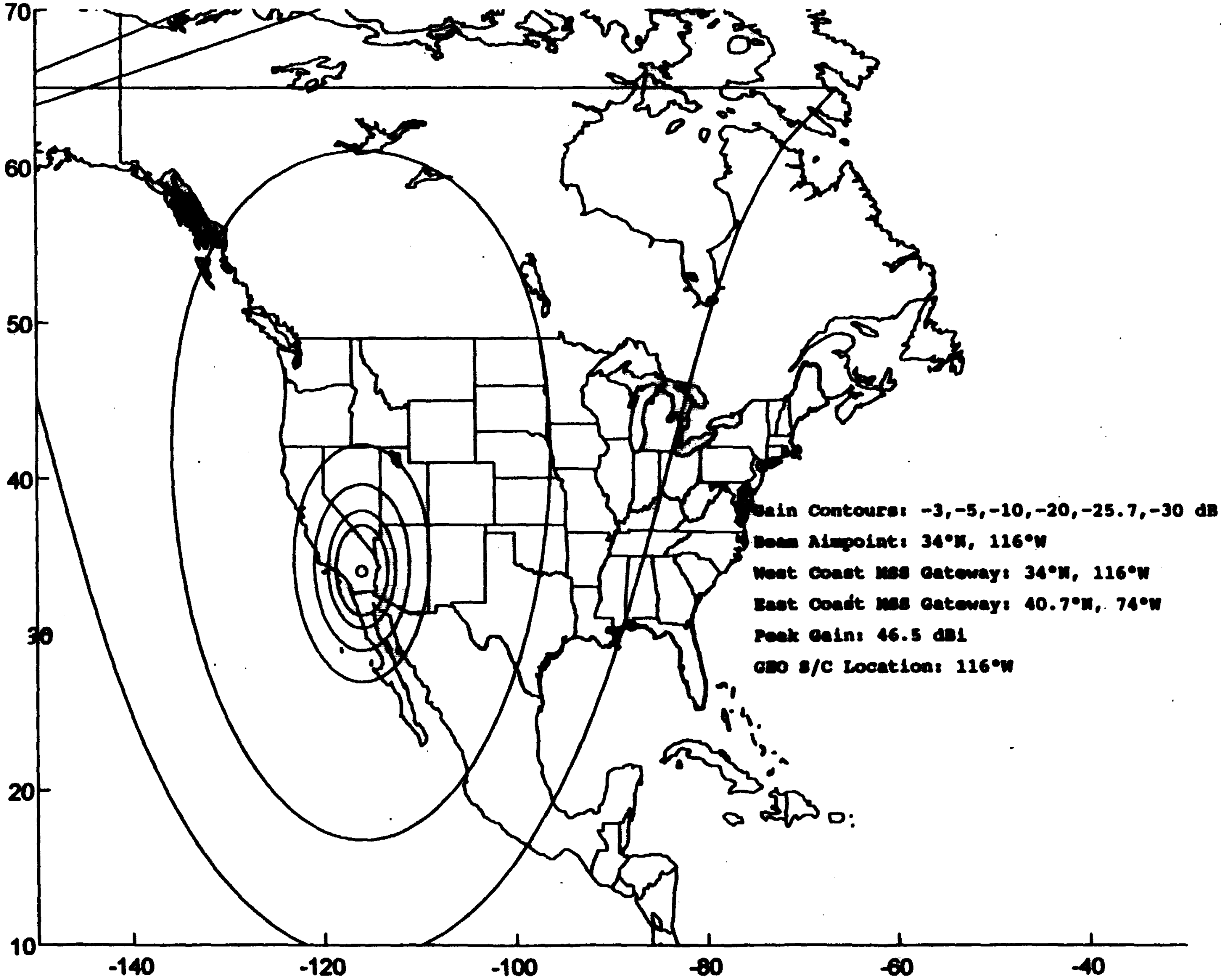
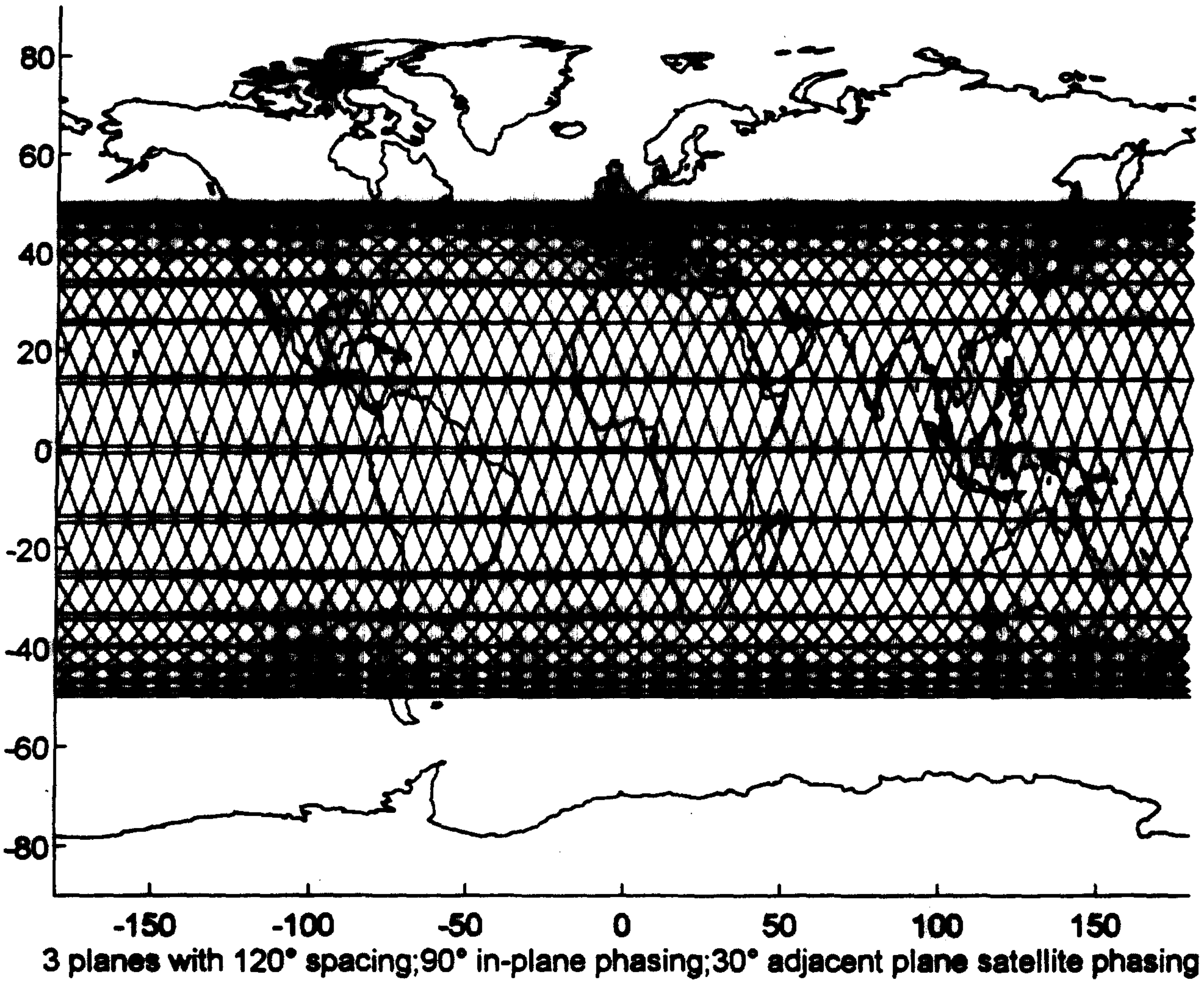


FIGURE 5.2
Groundtracks of 12-Satellite Odyssey Constellation



3 planes with 120° spacing;90° in-plane phasing;30° adjacent plane satellite phasing

Figure 5.3 - Use of Gateway Diversity to Avoid Excessive Interference between a Medium Earth Orbit (MEO) Mobile Satellite System and a Geostationary Fixed Satellite Service System

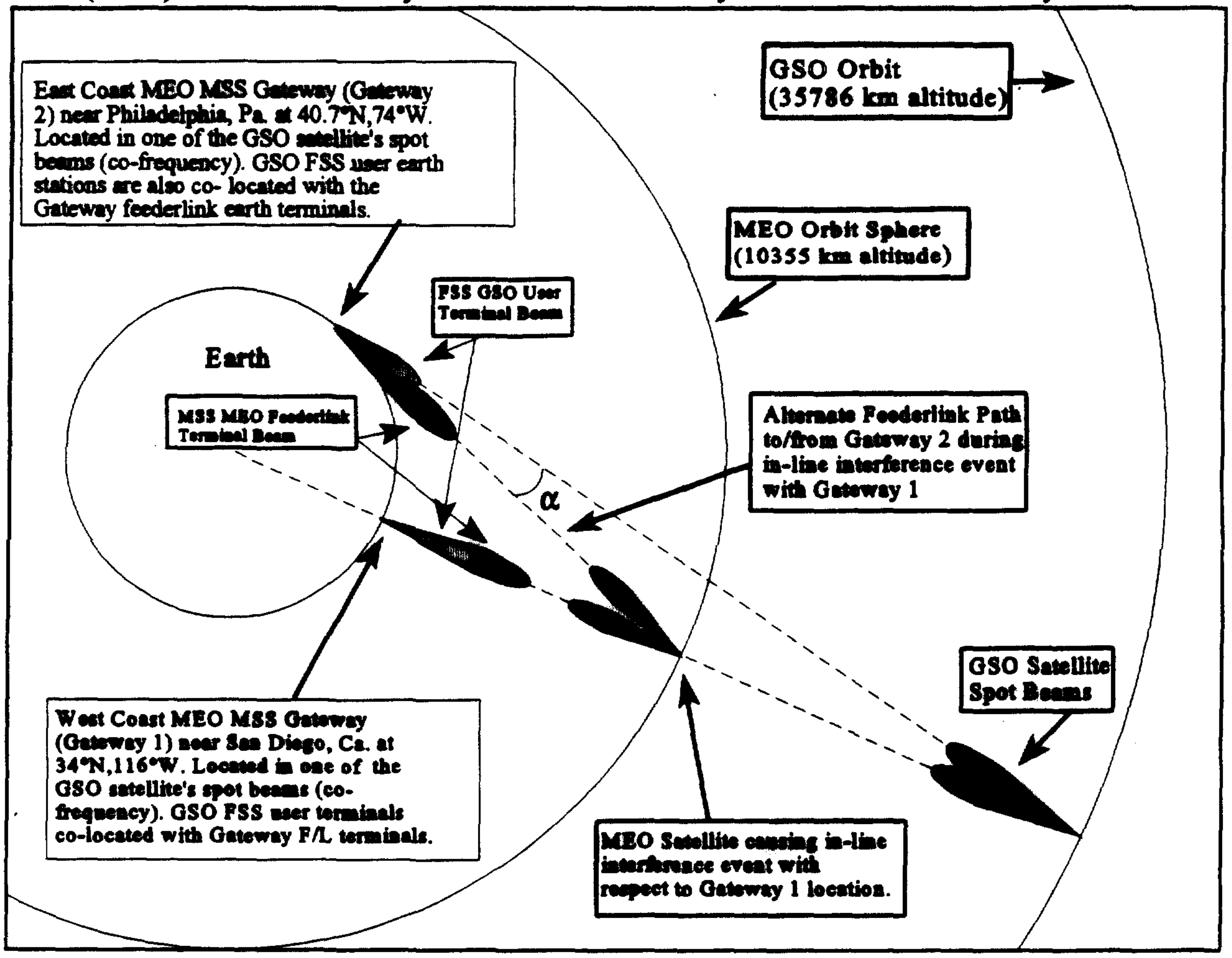


Figure 5.4(a) - Peak Interference Levels Occurring During In-Line Interference Event For Gateway 1 Feederlink Station Located On West Coast When Gateway 1 Is Providing Active Feederlink To MEO MSS Satellite (GSO Satellite Narrow Beam Case)

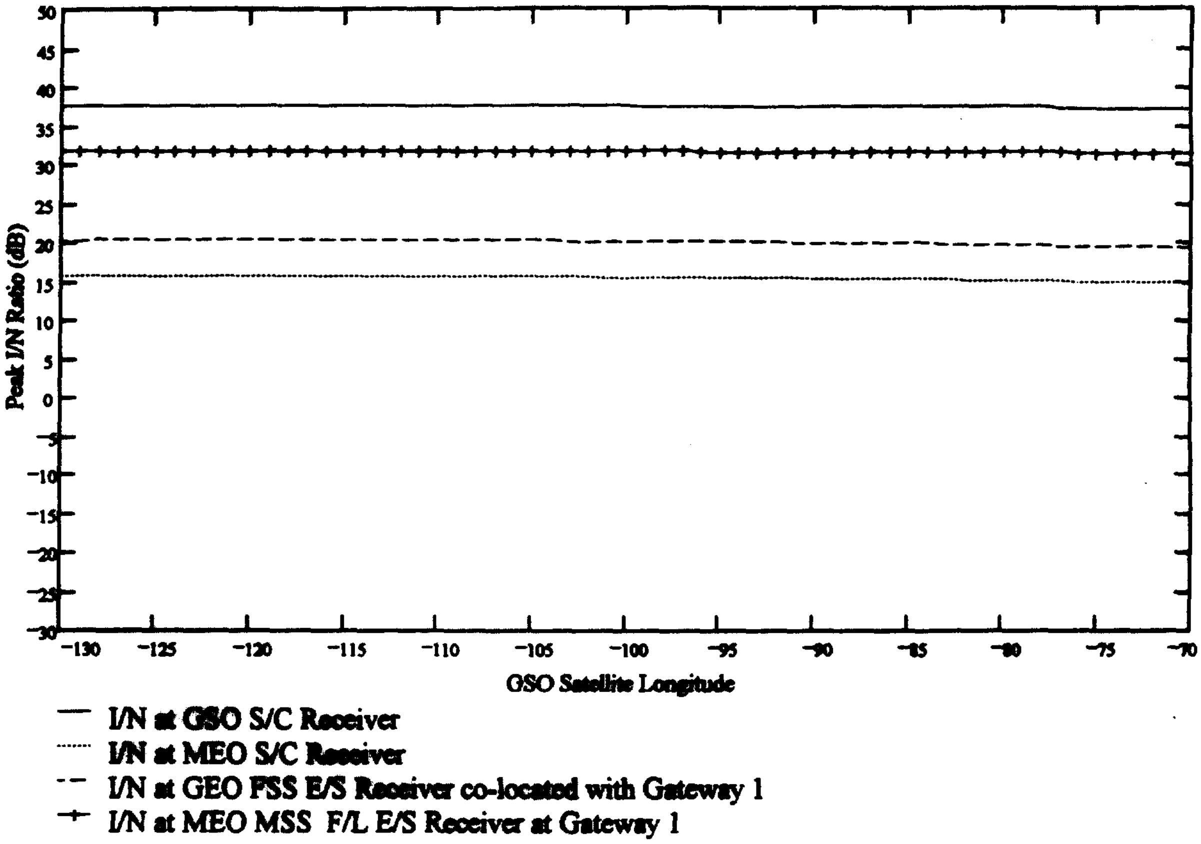


Figure 5.4(b) - Peak Interference Levels Occurring During In-Line Interference Event For Gateway 1 Feederlink Station Located On West Coast When Gateway 2 (East Coast) Is Providing Active Feederlink To MEO MSS Satellite (GSO Satellite Narrow Beam Case)

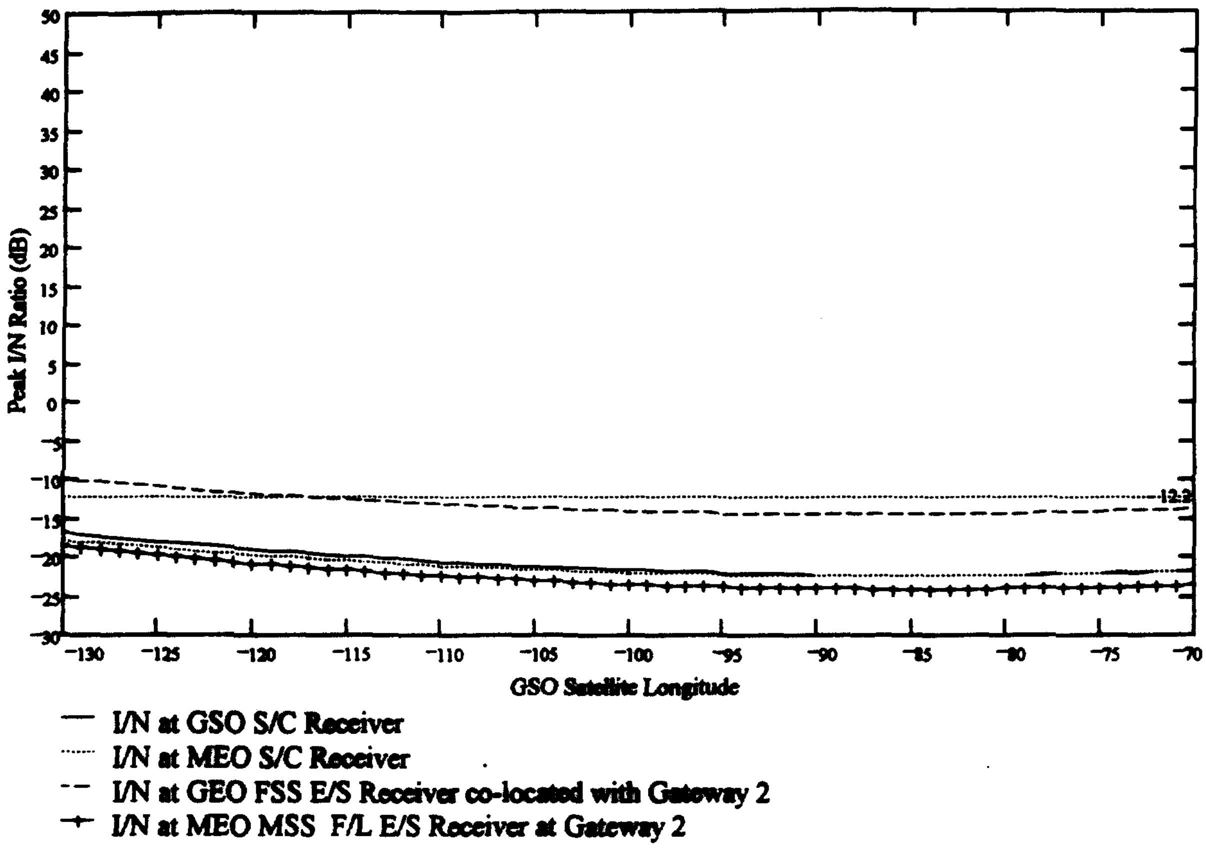


Figure 5.5(a) - Peak Interference Levels Occurring During In-Line Interference Event For Gateway 1 Feederlink Station Located On West Coast When Gateway 1 Is Providing Active Feederlink To MEO MSS Satellite (GSO Satellite Wide Beam Case)

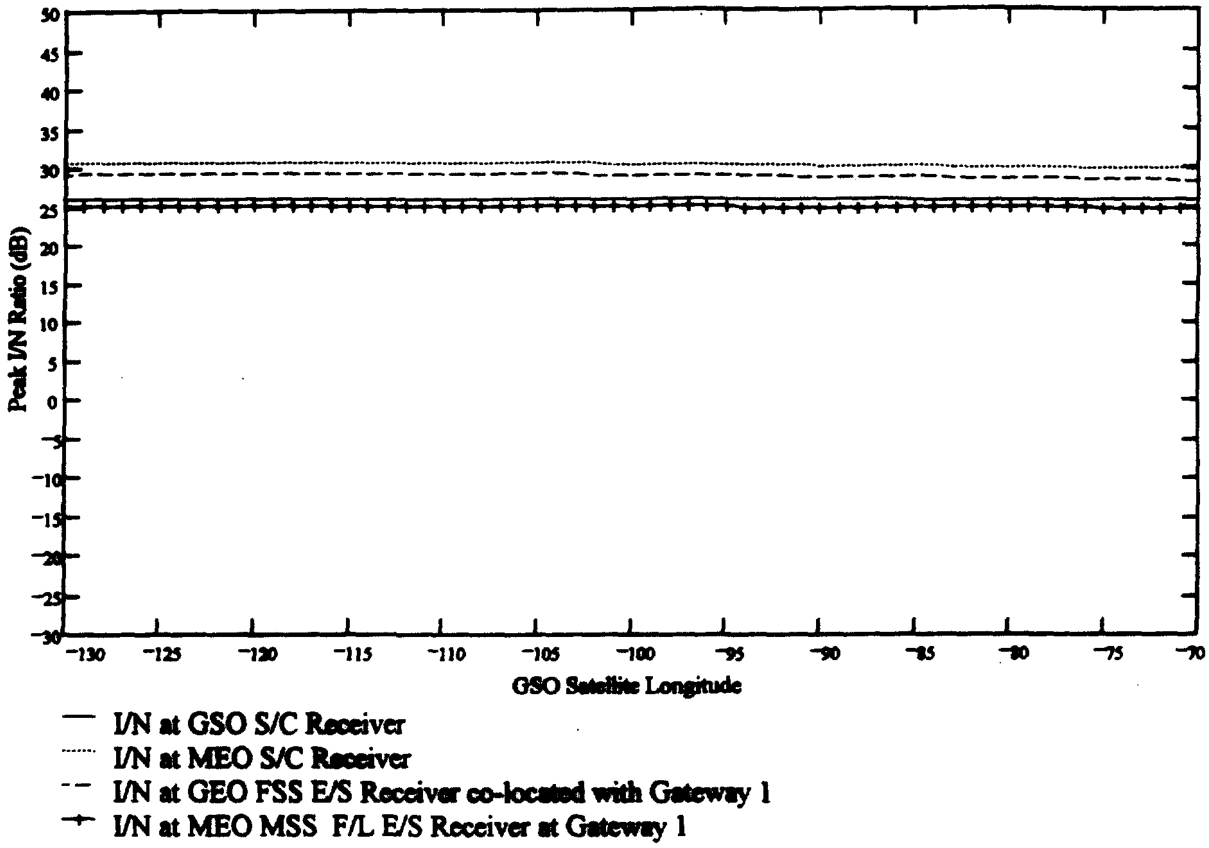


Figure 5.5(b) - Peak Interference Levels Occurring During In-Line Interference Event For Gateway 1 Feederlink Station Located On West Coast When Gateway 2 (East Coast) Is Providing Active Feederlink To MEO MSS Satellite (GSO Satellite Wide Beam Case)